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BREAKING-LOAD EVALUATION OF MODIFIED NAVY CRANE INSULATOR LINKS--ETC
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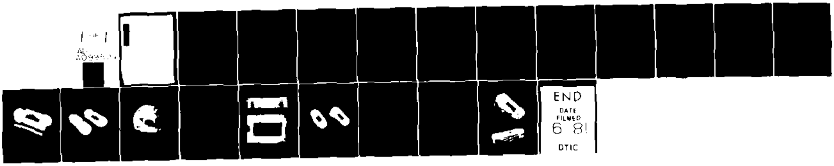

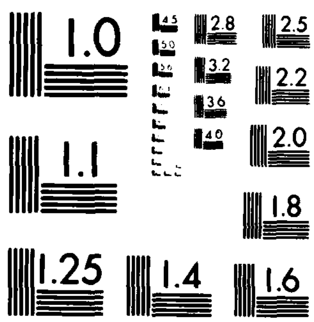

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An earlier study by NRL found that the 15 long ton Navy insulator link, as manufactured in accordance with MIL-L-24410 (SHIPS), was not "fail-safe" at crane loads of six times the rated load.

This report presents results on breaking loads for a series of modified Navy links. Recommendations are presented to either change the present MIL SPEC to achieve "fail-safe" design or to abandon the redundant band concept and increase the safety factor on crane insulator links.

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CONTENTS

BREAKING-LOAD EVALUATION OF MODIFIED NAVY CRANE INSULATOR LINKS

I. BACKGROUND

Development and early test results of Navy ship crane insulator links were described in 1967 [1]. Later, Military Specification MIL-L-24410 (SHIPS), "Link, RF High Voltage Insulator for Ship Cranes," dated 5 February 1970 [2] was issued which gives specifications for manufacturing, testing and shipping of these insulator links in three load capacities. The smallest, 15 long ton, version of this Navy developed link was evaluated, along with several commercially available crane insulators, in an earlier NRL report [3]. The Navy lifting link is the only one which was designed to be redundant or "fail-safe". This feature is achieved by concentrically winding two separate bands of fiberglass filament around two zinc-coated steel saddles. The two bands are separated by a silicone rubber spacer so that loads of less than the rated load are carried entirely by the inner band. The outer band then serves as a spare, or back-up, to support the crane load if the inner band fails. The links are not intended for continued use after failure of the inner band.

In the earlier NRL study [3], it was found that, at the load required to fail the inner band, nearly 20% of the total load was already being supported by the outer band. Under these severe overload conditions, the outer, or reserve band was unable to bear the full load when the inner band failed, so it too failed immediately. Thus the current design of the link is not truly "fail-safe" when an extreme overload fractures the undamaged inner band. The links are designed with a safety factor of 6 based on the rated load. The nominal 15 long ton link specifies a minimum breaking load of 210,000 lb for each band and is intended for use with loads up to 35,000 lb (15 long tons).

The specifications [2] indicate that both bands of the 15 long ton link are to be 9/16 inch in thickness. In actual practice the two bands are wound from equal lengths of 2-1/4 inch wide preimpregnated (E-glass with 26% resin) tape. The 15 long ton link requires one 72-yard spool of prepreg tape for each band. Measurement of the prepreg spool lengths has found that they actually contain more than the specified 72 yards minimum. Since the outer band is wound over the inner band and requires a longer length per layer, the outer band has a thinner cross-section than the inner band. This was the case with the links manufactured for use in the Navy and those tested earlier at NRL [3]. The thinner outer band further handicaps a "fail-safe" performance. The thickness of the bands is also dependent on the amount of resin that is squeezed out which is in turn dependent on the winding tension and ambient temperature during winding. Since the composite derives most of its tensile strength from the glass fibers, the number of layers of prepreg tape, or number of wraps, is more relevant than the thickness or total yardage of prepreg used.

II. INTRODUCTION

As a follow-on to the earlier work, NRL initiated a study to determine whether a reproportioning of the total yardage of prepreg tape in a link might render it truly "fail-safe" at the breaking load for the inner band. Such a modification might decrease the design safety factor of the inner band, but could increase the overall safety of the link as a complete unit. The electrical insulating quality of the link should be unaffected by such a modification.

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Calculations using data from the previous tests [3] indicated that removing about 20% of the tape from the inner band and adding it to the outer band might produce a "fail-safe" system. Four specimen configurations were chosen to bracket what was believed to be the calculated best ratio. Specifications were written and a contract awarded for the manufacture of five specimens of each of the four configurations. The specimen links were wound with a specified measured length of prepreg tape on the inner band. The remaining tape from the first 72-yard spool plus another full spool was then applied to the outer band. A silicone rubber spacer was used to separate the two bands as specified in the MIL SPEC. The manufacturing process was to be unchanged from that used normally except for the specified measured length applied to the inner band. Requirements for quality control tests, finish painting, and epoxy fill at the saddles were deleted from the MIL SPEC for these experimental specimens. A typical link is shown in Figure 1. The manufacturer counted and recorded the number of revolutions or layers of tape in each band. Detailed information for each specimen is shown in Table I.

In the Table, the first number of the specimen identification indicates the measured number of yards of prepreg tape wound on the inner band. The second number is the minimum yardage on the outer band (144 minus yardage on inner band). The final portion of the specimen designation is the individual specimen number. Any excess yardage on either spool was added on the outer band.

One specimen had been accidentally misaligned during the cure cycle. Such a link would normally have been rejected through visual inspection but in this case it was included by the manufacturer as an extra specimen so that we could determine what, if any, effect this obvious manufacturing defect might have on the load capabilities of the link. This "defective" link was designated 60-84-3X.

One specimen remained from the earlier study [3] and was used in the present study for comparison. This link, manufactured in accordance with the present standards, was designated 72-72-1, and denoted in the text as a "standard" link.

III. RESIDUAL STRESSES IN THE INSULATOR LINKS

Determining the breaking loads for the individual bands required sawing completely through one band on each side so that only the remaining band was capable of supporting the applied load. Sawing through the outer band was difficult since, due to residual stresses in the cured link, the saw cut would close up and bind the saw blade. Conversely, the saw cut on the inner bands would tend to open up and make continued sawing much easier. These residual stresses were measured on subsequent specimens by bonding strain gages on the bands before releasing the stresses with the saw cut.

Test results showed both bending and uniaxial stresses present in each band of the cured fiberglass composite. The inner band is in tension with a superposed bending moment adding more tensile stress on the innermost surface. The outer band is in compression with a similar bending moment adding compressive stresses to the outermost surface. Strain changes equivalent to tensile stresses in the range of 4.2 ksi were measured on the inner surface with the outer surface showing compressive stresses as high as 7.0 ksi. These residual stresses are relatively small and are in themselves insignificant to the overall load performance of the links. Such residual stresses are, however, interesting since they would tend to separate the two bands if debonding were to occur between the bands at the rubber spacer and steel saddles. Repeated field use may tend to cause deterioration of these bonds and further separation of the bands due to the residual stresses. This would decouple the bands and decrease the proportion of total load carried by the outer band and thus improve chances for "fail-safe" behavior in the link.

The earlier NRL study [3] included tests on three specimens which had been load cycled 20,000 times to the rated load before static tensile testing to failure. Re-examination of these data shows that the breaking loads for these three specimens fell in the extreme upper (higher load) portion of the

scatter band for the published data. Only one of these three specimens had been instrumented. Examination of the record for the instrumented specimen shows that the outer band remained unloaded until the total load on the specimen had reached 60 kips. The specimens tested in this study began loading the outer band at from 30 to 55 kips. This tends to substantiate the idea that normal release of residual stresses would decouple the bands and delay loading of the outer band. If true, this would also explain why the pre-cycled links performed so well under static loading in the earlier study [3].

IV. BREAKING STRENGTH FOR THE INDIVIDUAL BANDS

The "Quality Assurance Provisions" section of MIL-L-24410 (SHIPS) [2] requires that the two fiberglass bands each be loaded individually to failure. This is accomplished by sawing or cutting through one band so that the other may be tested separately to determine its breaking load. In this study the inner band of the first specimen from each group was tested in this manner. The outer band of the second specimen from each group was tested similarly.

Typical broken specimens from these tests are pictured in Figure 2. The saw cut band and the tensile tested band can be seen in the photograph. The specimens were tested at a loading rate of approximately 2,000 lb/sec over the linear elastic loading range.

Testing the outer band separately causes severe shear stresses in the metal spool, or saddle, flange. The spreading of the band shears the flange between the two inspection holes. Such failures occur frequently; one of the worst cases is illustrated in Figure 3.

Results from tests of the individual bands are tabulated in Table I and shown plotted in Figure 4. Each data point in Figure 4 represents one test with the lines drawn arbitrarily to represent data trends only. The breaking loads, on the ordinate, are plotted as a function of different, but related abscissas. The graph on the left, A, is plotted on the basis of yardage of prepreg tape on each individual band. The double abscissa is arranged so that the total yardage in the two bands will add up to 144 yards, two 72 yard spools. Each point on the axis represents a possible yardage ratio for the two bands. The breaking loads for the two bands of a single specimen configuration will thus fall on the same abscissa value. This type of plot best illustrates the relative strengths of the two bands and the cross-over point when one band becomes stronger than the other.

It was originally believed that plotting the data normalized as to the number of turns, or layers of tape, might cause the data to all fall on one curve. However, Figure 4b shows that, when plotted as a function of layers, the strength data for the outer band falls below those for the inner band. In other words, the outer band has less strength per layer of tape than the inner band. This difference is very noticeable when the breaking load per layer values are compared directly. These calculated values are listed in Table I. The material in the outer band is on the average only 80% as efficient as that in the inner band.

The reduced performance of the outer band can be explained. The outer band is supported by the fiberglass of the inner band and rubber separator while the inner band is supported directly by the hub of the saddle. Under high loads the materials beneath the outer band would tend to compress and give less support to the outer band. The stiff curved composite would then be loaded with a bending moment in addition to the tensile loading. The breaking load as recorded and plotted does not take the bending moment into consideration. This is justificable since in actual service one is only concerned with the crane load required to fail the link, not the components of the stresses acting on the link.

The method of construction, as discussed earlier, puts the excess yardage, anything over the minimum 72 yards, from both spools of prepreg on the outer band. The outer band actually contains more than is indicated in Figure 4a, therefore, the data points for the outer band should realistically be

moved toward the left, forcing the cross-over or equal strength region further toward the lefthand side of the graph. In Figure 4b the abscissa is based on the actual count of the specimen turns or layers of tape for each band.

When considering all the "breaking-load-per-layer" values in Table I, in spite of the scatter, one can see a trend for the values to decrease with increasing number of layers. In other words, forty layers could be expected to give somewhat less than twice the breaking load of twenty layers. Although the extended curves in Figure 4b, as will also be the case with Figures 7b and 8b, must pass through the origin, they are probably not a straight line. Therefore the straight lines, drawn in the figures to indicate data trends over only a small portion of the entire curve, were not forced to fit through the origin.

The defective specimen 60-84-3X, mentioned earlier, is shown in Figure 5. Figure 5a illustrates the misalignment of the metal saddles, and 5b shows a close-up of the puckered layers of curved prepreg tape. The lay-up in the inner band appeared to be more disarranged so it was tested separately to produce a worst case situation. The result of this test on the defective specimen is plotted with the data in Figure 4. The point falls within the lower portion of the normal data scatter band. Therefore one would conclude that small distortions in the layers should not cause concern.

V. BREAKING STRENGTH FOR THE COMPLETE LINKS

Four electrical resistance foil strain gages, with a gage length of 1/2 inch, were bonded to each of the remaining insulator links. The gages were bonded with Epon 828 epoxy resin and Eastman Tetraethylenepentamine hardener mixed with 100 parts resin to 12 parts hardener. A gage was bonded to each band near the center of the straight section on both sides of the link. The gages were placed near the center line of each band axis to measure the uniaxial tension and eliminate the bending stresses as much as possible. The gage locations can be seen on the photographs of the broken links shown in Figure 6. Each gage was connected to an Elcore Model BSC-416C signal conditioning network, the output of which was then fed into a Y-axis on one of two HP Model 7045 X-YY plotters. Each specimen link was loaded in a 400 kip capacity Baldwin universal testing machine. The output of a linear displacement transducer which was connected to the dial indicator of the testing machine was used to drive the X-axis on two X-YY recorders. The strain from the inner and outer band from one side of the specimen was recorded on one plotter and the two strains from the other side were similarly recorded by the second plotter. These strain plots were used to determine the relative load supported by the two bands on each side of the link as well as the breaking loads. Once the control valve of the testing machine was set it was not changed through the entire test. The same valve setting was used for all tests in a series. The indicated loading rates were determined by timing the load indicator dial with a watch. These rates were measured during the linear part of the loading curve when the bands were supporting the load jointly. When the inner band failed the load was allowed to drop off and then to be picked up again by the outer band as the testing machine continued to run and increase displacement. In cases where the outer band did not pick up and support a load of its own, the breaking load of the outer band was estimated and the point plotted and indicated by an arrow through the point.

A typical X-YY load-strain plot is shown in Figure 7. In this particular specimen, 50-94-5, the outer band began loading at a total specimen load of 30,000 lb (point A). When the inner band failed (point B) the entire load is transferred to the outer band where the strain suddenly increases and the total load drops off (point C). As the testing machine continues to run, the total load, now supported by the outer band, increased to finally fail the outer band (point D) at a load greater than that at which the inner band had failed. This specimen exhibited the desired "fail-safe" characteristic.

The third specimen from each group was tested intact at a loading rate of 2,000 lb/sec. This was the same rate used in breaking the individual bands. The data from this series of tests are tabulated in Table I and plotted on Figure 8 through which lines were again drawn arbitrarily to show trends. The

poorer relative performance of the outer band is more apparent when the data is plotted on the basis of the number of layers of tape as in Figure 8b. Comparing Figure 8 and Figure 4 one sees that in reference to the total breaking load, the inner band of the intact link performs better than the separate band; but, the outer band of the intact link performs worse than the separate band. These differences are easily explained. The inner band of the intact specimen appears stronger since the outer band is already supporting part of the load when it fails. Close examination of the broken specimens revealed that the outer band always fails at the same location as the inner band failure. The inner band fails at the tangent to the metal saddle, separates and then does not support the outer band at that point. This introduces extra bending stress in the stiff outer band causing premature failure at the same location. This effect was especially evident in specimen 55-89-4 to be discussed later in more detail.

One unbroken specimen remained from the earlier study [3]. This "standard" specimen was tested as described above and the results plotted on Figure 8 for comparison. Standard specimens are made with one spool of 72+ yards of prepreg tape on each band. No record was kept as to the number of layers on each band, but the number of layers was estimated so that the data could be plotted for comparison. The specimen was designated as 72-72-1 in Table I.

To allow a longer time under load for internal creep and load adjustment, the fourth and fifth specimens of each group were tested at a lower rate, approximately 200 lb/sec. These data, plotted in Figure 9, show strong loading rate dependence when compared to the faster loading results of Figure 8. In the earlier study [3] strain gage indicators were balanced and recorded manually, therefore a slow stop and start loading was applied. This earlier data should then compare favorably with the slower loading data of this study. The average values from the earlier work with the standard links are shown plotted in Figure 9 for comparison, using the estimated numbers of layers as before.

At the faster loading rate, Figure 8, the breaking strength of the outer band seemed only slightly dependent on the layers or yardage in the band. The inner band, however, showed a strong dependence on the number of layers or yardage. At the slower loading rate these trends seem almost reversed and it is the outer band that is more strongly influenced by the amount of material in the band. At present there is probably not enough data to verify these differences which may in fact be due only to data scatter. On the other hand, it is plausible that the slower loading rate could allow time for load adjustments within the link and more flow in the rubber spacer which is extruded through the inspection holes in the saddles. It was observed that the amount of rubber extruded through the inspection holes is increased at the lower loading rate. As shown in the last column of Table I, the percentage of the total load supported by the inner band increases at the lower loading rate and tends to decrease with decreased number of layers of tape on the inner band.

The percentage of total load supported by the inner band was calculated from the strain gage records for each test. As mentioned earlier the number of layers of prepreg was thought to be more relevant than the cross-sectional area of the bands. Considering the number of layers, N, to be proportional to or representative of the area, we can say that

$$P \propto \epsilon N$$

where P and ϵ represent the load and strain. Therefore, using the subscripts o and i to represent the outer and inner bands respectively, it can be shown that

$$\epsilon_i/\epsilon_o = P_i N_o / P_o N_i$$

or

$$P_o = \epsilon_o N_o P_i / \epsilon_i N_i$$

The total load, P_T, then becomes

$$P_T = P_i + (\epsilon_o N_o P_i / \epsilon_i N_i)$$

and the percentage of total load supported by the inner band can be written as

$$100\ P_i/P_T = 100/[1 + (\epsilon_o N_o/\epsilon_i N_i)]$$

The last column in Table I is calculated using the above formula with strain values from the test records and number of layers as also shown in Table I.

One specimen, number 55-89-4, is of particular interest. It was one of the two specimens that was actually "fail-safe". Its outer band had the highest breaking load of all specimens tested intact. The fracture mode was unusual with about one-half the outer band breaking at each end of the link as shown in Figure 10. Closer examination revealed that the inner band had failed in an identical manner. This is supporting evidence that the failure on the inner band initiates failure in the outer band at the same location, as pointed out earlier in this report.

IV. DISCUSSION OF RESULTS

In the original development and tests of the Navy insulator link [1], the links were loaded to the rated load; the inner band was then cut so that the entire load was transferred from the inner to the outer band. At the rated load these links were "fail-safe". In fact every link tested in this present program would have been redundant at a load of 35,000 lb. However, if an undamaged intact link is loaded to failure, i.e., at a load usually more than six times the rated load, only two specimens in this study could be considered redundant, specimens 50-94-5 and 55-89-4. These were the only specimens for which the outer band failed at a load greater than the total load being supported when the inner band failed.

For a redundant, or fail-safe, design at the breaking load for the inner band, the outer band must contain a substantially larger amount of prepreg tape than the inner band. This is true for at least three reasons: (1) The outer band has a larger circumference than the inner band so requires more tape to produce an equal number of layers. (2) Material in the outer band is less efficient and has a lower breaking load per layer when the bands are tested separately. (3) Failure in the inner band initiates a premature failure of the material in the outer band. A fourth reason might also be added, since the outer band would be more vulnerable to nicks and physical damage during in-service use. In addition, the inner band does not need to be as heavy since at the near-failure loads part of the total load is already being supported by the outer band.

The present design of the flanges on the metal saddles for the 15-ton link is at best marginal at the breaking strength of the link. Figure 3 shows the type of failure very common in tests of the outer band. This may not be important, however, since the links are not to be used with damaged inner bands so the outer band should only experience such high loads once, if ever, during their service life. The fact that they survive may be sufficient.

The question may be raised whether it is advisable to require that these links be redundant at a load six times the normal working load, or are we really only concerned about failure in the inner band at loads equal to or below the rated load. An obvious solution is to make the link as one continuous band with the present quantity of material, producing a safety factor so large that it would never fail before other components of the crane. The Navy link would then offer no advantage over the several other such insulator links presently available on the commercial market. If the unique redundancy of the present design is no longer required, it may prove more cost effective for the Navy to purchase on the commercial market rather than contract for specially manufactured links.

Recommendations will be made allowing the Navy the choice to either improve the present MIL SPEC and make the Navy link truly "fail-safe" at a load six times the rated load, or to abandon the "fail-safe" concept and simply increase the safety factor for lifting links.

If the decision is made to retain the "fail-safe" idea, and improve the present MIL SPEC, these recommendations would increase the overall safety of the link but reduce the safety factor for the inner band if tested separately; however, under service conditions the inner band would never be loaded without the presence of the outer reserve band to support at least 20% of the total load at failure. Testing and specifying breaking loads for the inner band alone, therefore, seems irrelevant, unless the load supported by the outer band is taken into consideration. The outer band, on the other hand, must support the entire crane load if the inner band fails. Its individual strength is important.

When testing the outer band of a link in which the inner band has already failed, as in all specimens numbered 3, 4, and 5 in this study, one does not know how much load may still be supported by the failed inner band. To be conservative it must be assumed that for a service failure no load will be supported by a failed inner band. Cutting through the inner band before testing does not produce the degradation in the strength of the outer band caused by the inner band failure. For the more slowly loaded specimens, this degradation is usually less than 20%.

VII. RECOMMENDATIONS FOR INSULATOR LINK MODIFICATIONS

Based on the limited results of this testing program with the 15 long ton link, it is recommended that the present specifications reflect the following changes in order to insure a "fail-safe" criteria at crane loads six times the rated load.

1. The layers, or yardage, of prepreg tape should be specified rather than the cross-sectional thickness of each band.

2. The inner band on the 15-ton link should contain 50 yards or 59 layers of prepreg with at least 94 yards or 85 layers on the outer band. This assumes, of course, that the present 144 minimum total yardage is maintained.

3. The present specified minimum breaking load for the inner band, tested separately, (210×10^3 lb) be reduced by about 20% to 170×10^3 lb. The similar requirement for the outer band should be increased by about 20% to 250×10^3 lb. If the link is tested intact, the inner band should still be required to fail at a minimum total load of 210×10^3 lb.

4. Since most failures in the inner band occur near the point of tangency to the saddle's spool, moving the inspection holes by increasing the included angle between them would strengthen the flange and still allow for periodic inspection. If such inspections are not required, elimination of the holes would be recommended. This may be preferred to specifying thicker material in the saddle flanges, which would increase the overall link thickness and decrease present clearances.

If the "fail-safe" phenomenon is to be forsaken in favor of a higher safety factor the following is recommended:

5. The Navy should adapt a commercially available crane insulator link for its own purposes. These are presently manufactured with safety factors as high as 10 or 12 times the rated load.

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3. Seibert, E. R. and Smith, H. L., "Effect of Loading and Environment on the Strength of Insulated Lifting Links," NRL Memorandum Report 3765, April 1978.

TABLE 1 — Individual Specimen Details and Test Data

Specimen Identification: Group Designation: Yards Prepreg on Inner Band	Specimen Identification: Group Designation: Minimum Yards Prepreg on Outer Band	Specimen Number	Number of Layers of Prepreg Tape: Inner Band	Number of Layers of Prepreg Tape: Outer Band	Tensile Test Method	Total Breaking Load (lb): Inner Band	Total Breaking Load (lb): Outer Band	Breaking Load Per Layer of Prepreg (Ksi/N): Inner Band: Individual	Breaking Load Per Layer of Prepreg (Ksi/N): Inner Band: Avg.	Breaking Load Per Layer of Prepreg (Ksi/N): Outer Band: Individual	Breaking Load Per Layer of Prepreg (Ksi/N): Outer Band: Avg.	Percent of Total Breaking Load Supported by Inner Band
		1	59	96½	loaded inner band only at approx. 2,000 lb/sec	208,000	—	3.53		—		100.0
		2	59	99½	loaded outer band only at approx. 2,000 lb/sec	—	285,000	—		2.86		—
50	94	3	59	96½	loaded link intact at approx. 2,000 lb/sec	210,000	195,500	3.56		2.03		65.8
		4	59	96½	loaded link intact at approx. 200 lb/sec	268,000	246,000	4.54	4.06	2.55	2.39	75.2
		5	59	96½	loaded link intact at approx. 200 lb/sec	241,500	249,000	4.09		2.58		76.5
		1	63	91½	loaded inner band only at approx. 2,000 lb/sec	200,000	—	3.17		—		100.0
		2	63	90	loaded outer band only at approx. 2,000 lb/sec	—	236,000	—		2.62		—
55	89	3	63	98	loaded link intact at approx. 2,000 lb/sec	250,500	201,000	3.98		2.05		55.8
		4	65(?)	92	loaded link intact at approx. 200 lb/sec	255,500	281,000	3.93	4.01	3.05	2.30	80.7
		5	63	94	loaded link intact at approx. 200 lb/sec	260,000	170,000↓	4.13		1.81		79.0
		1	67	85	loaded inner band only at approx. 2,000 lb/sec	241,500	—	3.60		—		100.0
		2	67	87	loaded outer band only at approx. 2,000 lb/sec	—	252,000	—		2.90		—
60	84	3	67	83	loaded link intact at approx. 2,000 lb/sec	281,000	211,000	3.15		2.54		71.3
		4	67	84½	loaded link intact at approx. 200 lb/sec	250,500	229,000	3.42	3.41	2.71	2.70	79.2
		5	67	86	loaded link intact at approx. 200 lb/sec	260,000	246,000	3.67		2.86		77.6
		3X	67	86	loaded inner band only at approx. 2,000 lb/sec	221,500	—	3.31		—		100.0
		1	73	77	loaded inner band only at approx. 2,000 lb/sec	252,000	—	3.45		—		100.0
		2	73	78	loaded outer band only at approx. 2,000 lb/sec	—	208,000	—		2.67		—
65	79	3	73	82	loaded link intact at approx. 2,000 lb/sec	285,000	190,000↓	3.90		2.32		69.3
		4	72½	79½	loaded link intact at approx. 200 lb/sec	270,500	160,000↓	3.73	3.76	2.01	2.46	81.4
		5	73	79	loaded link intact at approx. 200 lb/sec	267,000	240,000↓	3.66		3.04		81.8
72+	72	1	≈85	≈70	loaded link intact at approx. 2,000 lb/sec	258,000	*180,000*	*3.04*		2.57		87.6

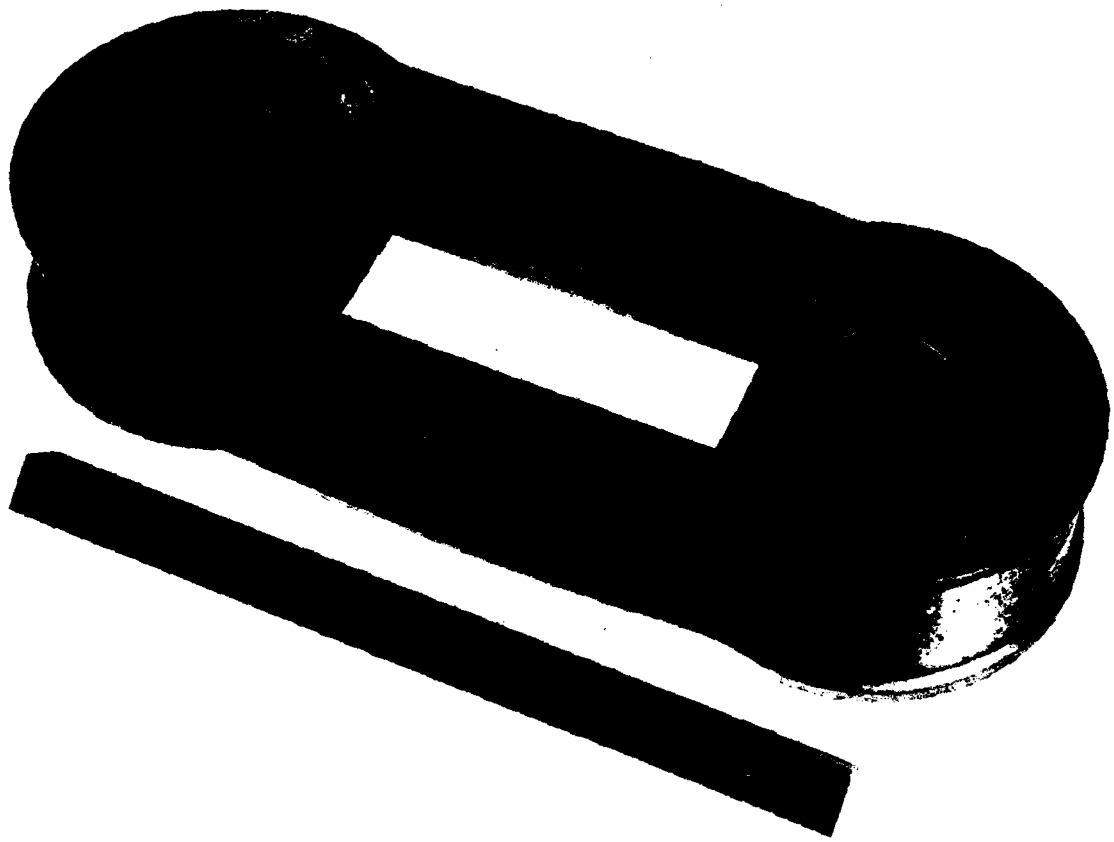


Figure 1 — Typical 15 long ton link as used in this study, without the standard paint and epoxy fill (specimen number 50-94-3)

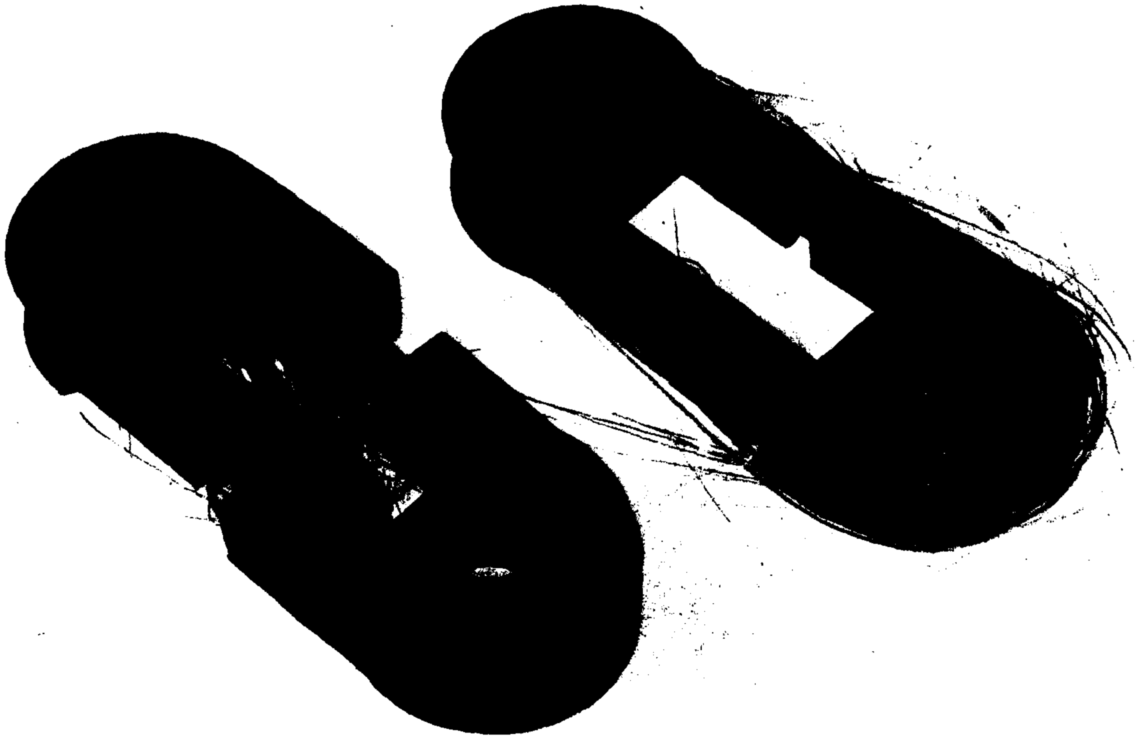


Figure 2 — Typical failed specimens with bands tested separately, (specimen numbers 50-94-1 and 50-94-2 on which the outer and inner bands, respectively, had been saw cut).

Figure 3 — Testing the outer band separately often caused failure in the saddle flange between the inspection holes. One of the worst cases is shown here (specimen 65-79-2).

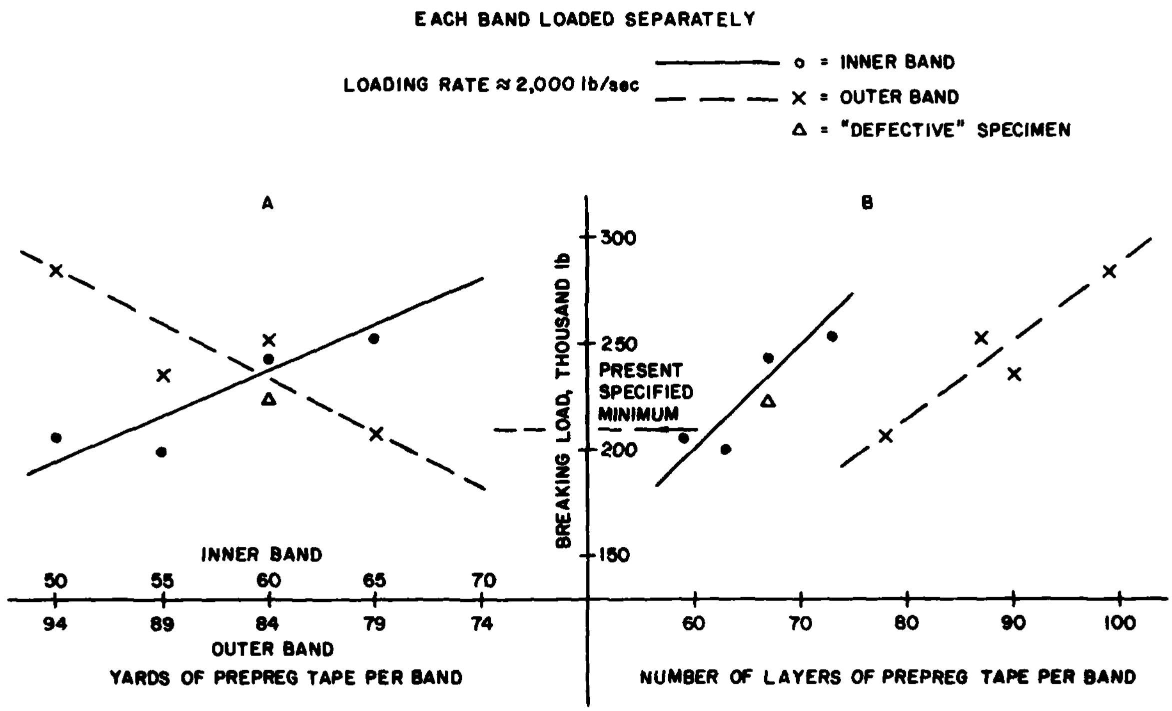
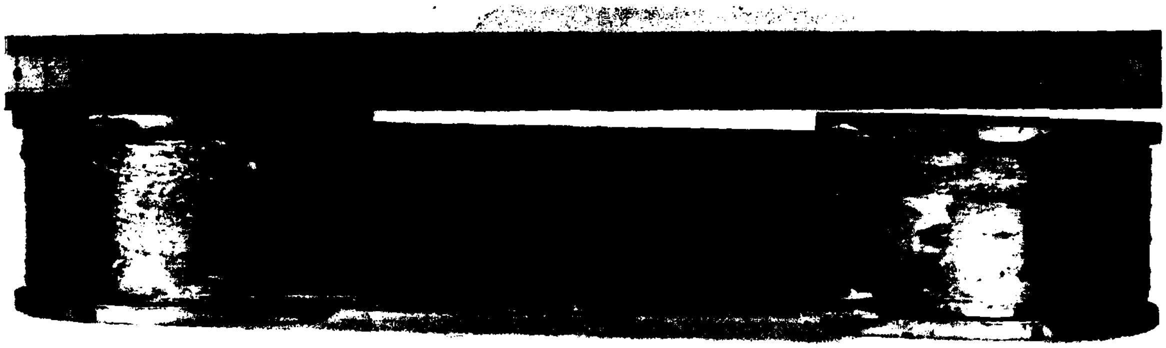
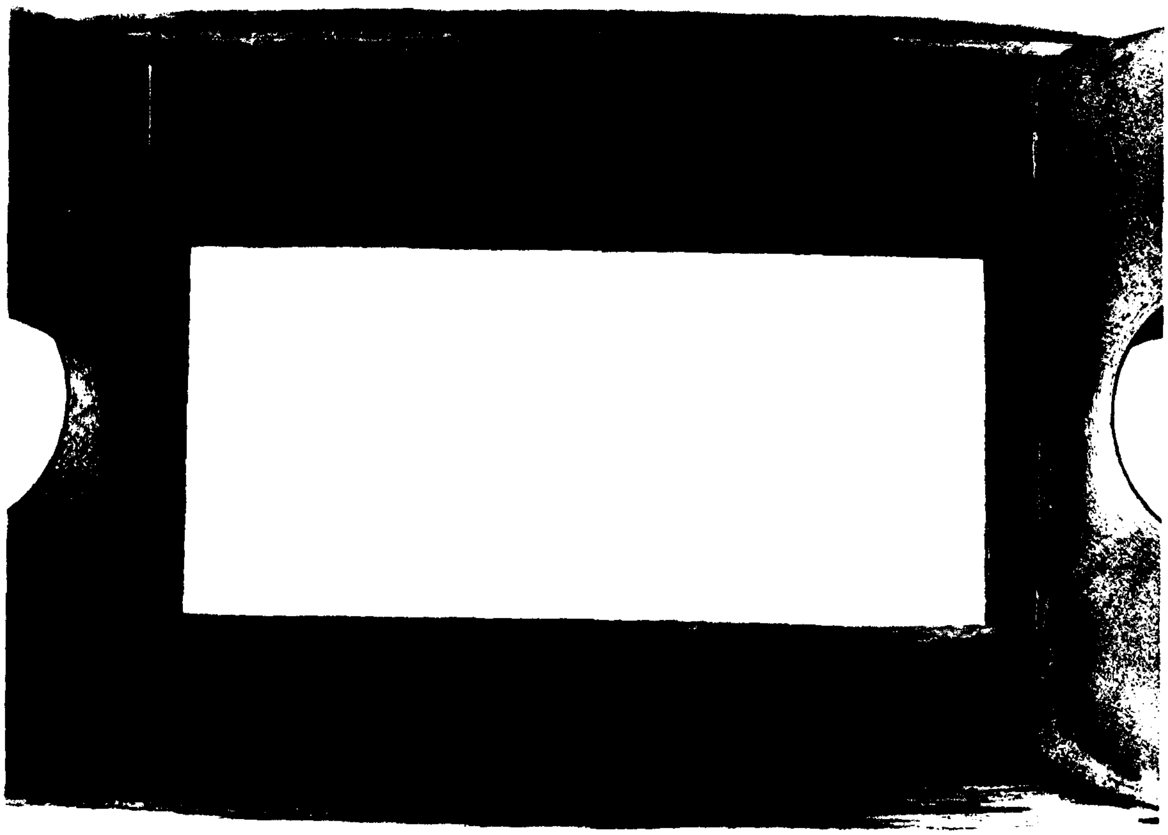


Figure 4 — Results of testing inner and outer bands separately



(a)



(b)

Figure 5 — Specimen 60-84-3X contained manufacturing defects caused by misalignment of the saddles during curing. A shows the misalignment causing the distorted tape layers shown in B

Figure 6 — Failed instrumented specimens, typical of those tested with both bands intact (specimen numbers 50-94-3 and 50-94-4)

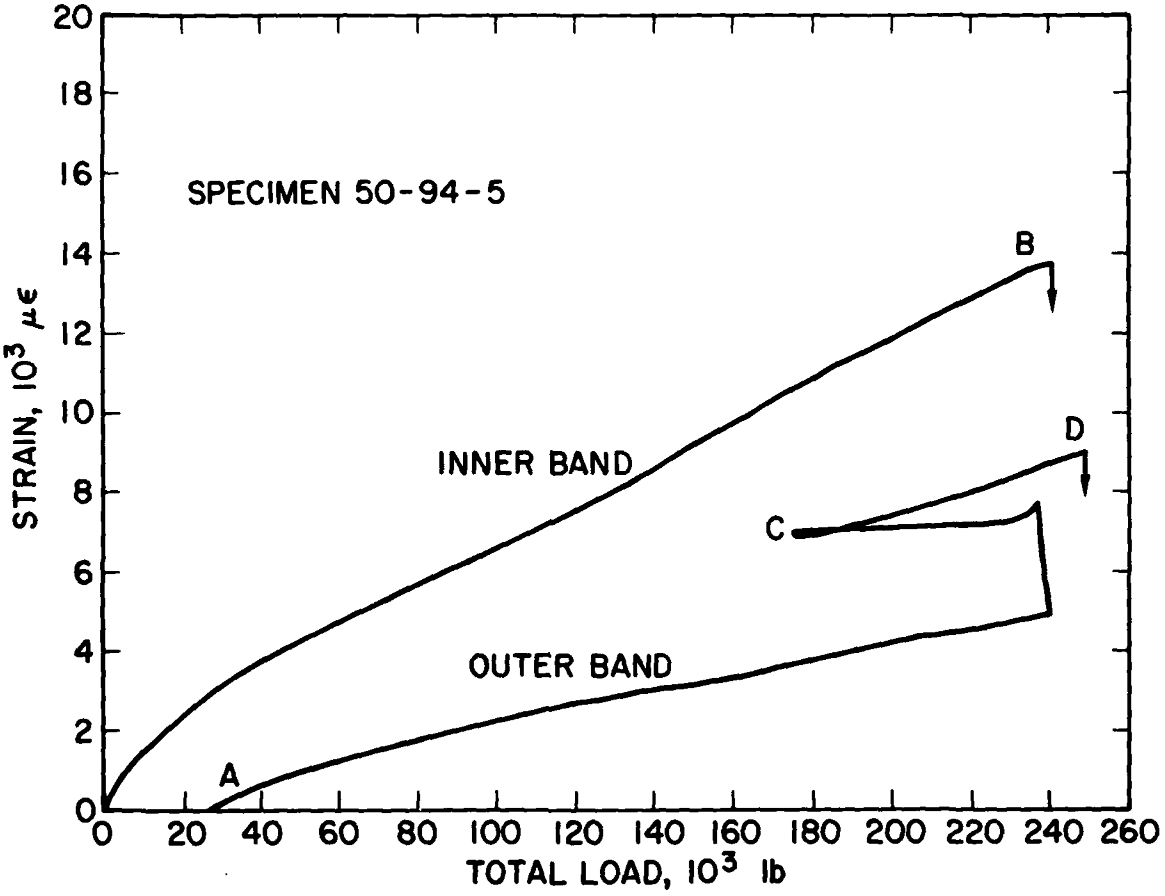


Figure 7 — Load-strain record for specimen 50-94-5

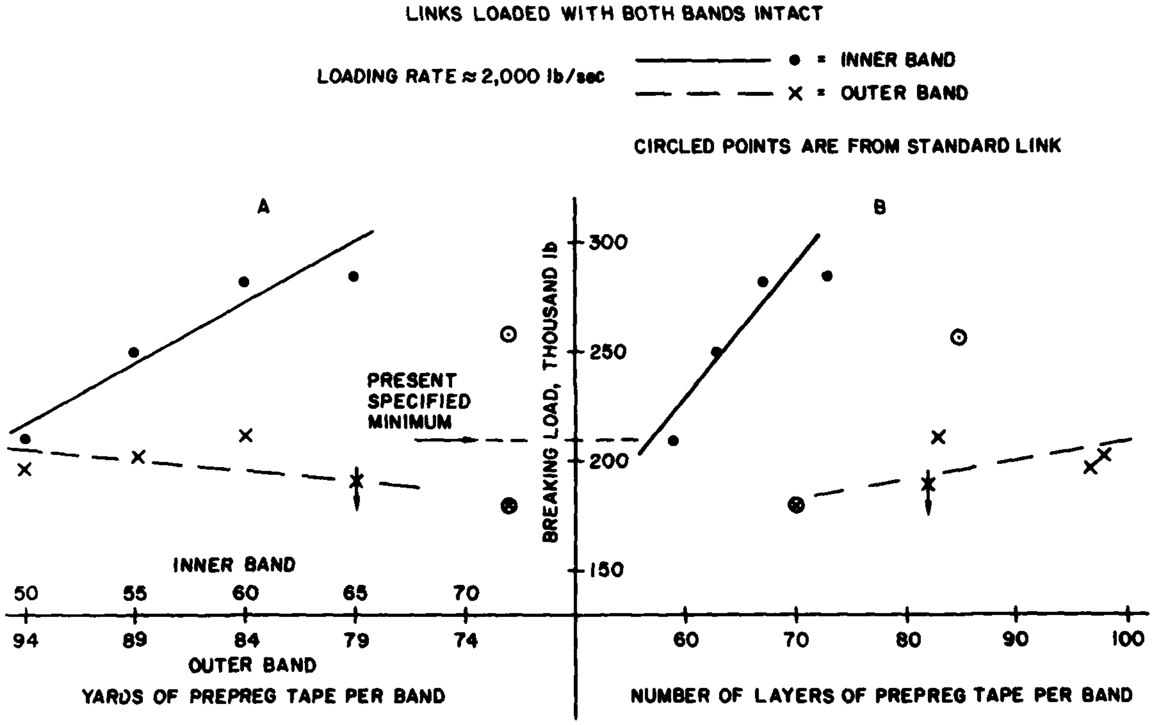


Figure 8 — Results from testing with both bands intact at a loading rate of 2,000 lb/sec

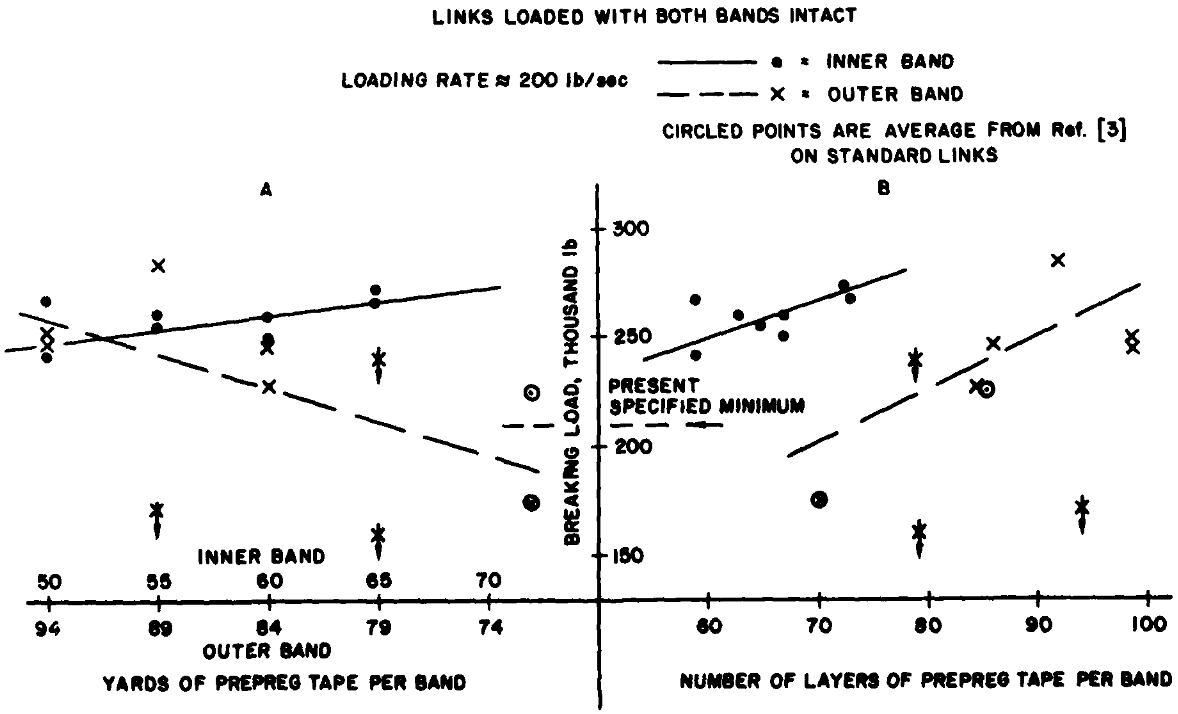
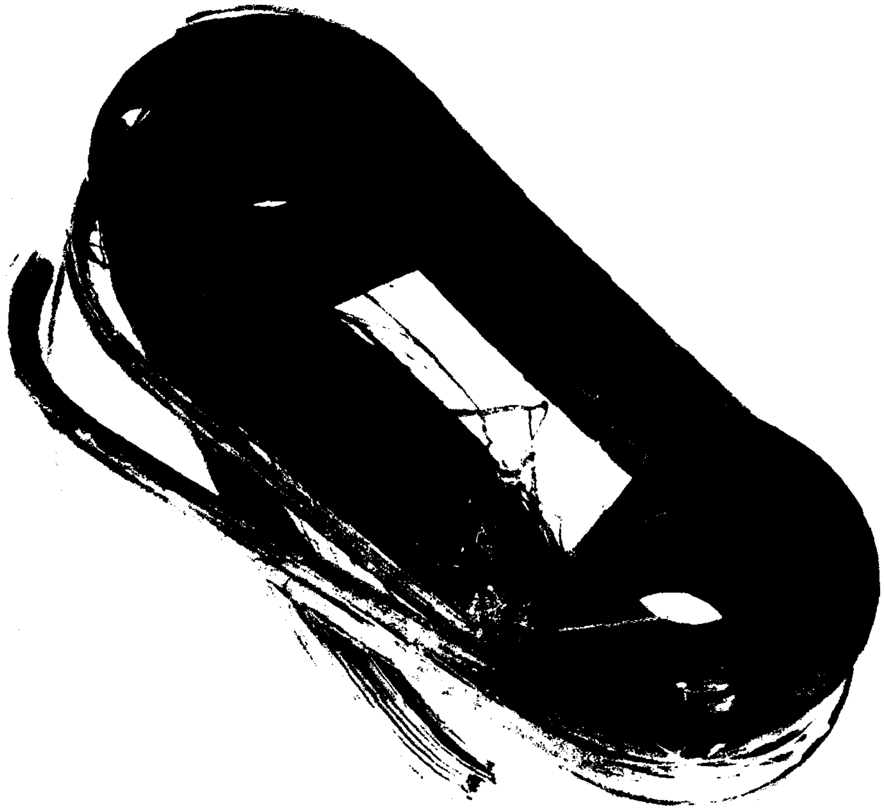


Figure 9 — Results from testing with both bands intact at a loading rate of 200 lb/sec



(a)

(b)

Figure 10 — Two views of specimen 55-89-4 in which portions of both bands failed at the same two locations

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